STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

Report of Investigations No. 96

THE GROUND-WATER SITUATION IN THE CIRCLEVILLE AREA, PICKAWAY COUNTY, SOUTH-CENTRAL OHIO

by

Stanley E. Norris
U.S. Geological Survey

Columbus
1975

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CONTENTS

FIGURES

TABLE

THE GROUND-WATER SITUATION IN THE CIRCLEVILLE AREA, PICKAWAY COUNTY, SOUTH-CENTRAL OHIO

by

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ABSTRACT

In the Circleville area in Pickaway County, south-central Ohio, industrial wells yield 8 million gallons per day (3.03 x 10^4 cubic meters per day) from sand and gravel outwash deposits in the Scioto River valley. Ground-water levels in the pumped area have been declining since pumping began in the mid-1950's, declining from 40 to 45 feet (12 to 14 meters) below land surface to 75 to 80 feet (23 to 24 meters) near the center of the cone of influence. Transmissivities at two closely spaced pumping centers were determined by analysis of the cone as 3,575 and 6,100 feet squared per day (332 and 567 meters squared per day), respectively. The hydraulic conductivity of the sand and gravel deposits is about 60 feet per day (18 meters per day). The wells are relatively far from the Scioto River, and most of the water withdrawn is from regional underflow, which is intercepted in transit to the stream. Yields of wells closest to the river are sustained, in part, by induced infiltration. This component is expected to increase as the cone of influence grows in response to withdrawal by industry. For optimum use of the aquifer, future pumping could be spread over a larger area, and new wells could be drilled outside the present cone of influence. Elsewhere in the Circleville area, sites are underlain by excellent aquifers, which are capable of yielding much more water than is being withdrawn at the present time.

INTRODUCTION

In the mid-1950's E. I. du Pont de Nemours & Co. built a plant for the manufacture of plastic film at a site about 2 mi (3 km)[1] southwest of Circleville, Ohio, on a high-level sand and gravel outwash terrace overlooking the Scioto River. Wells drilled for water supply range in depth from 116 to 176 ft (35 to 54 m) and are screened in sand and gravel deposits above the shale bedrock. When pumping began, about 1956, the water level in the wells was 40 to 45 ft (12 to 14 m) below land surface. Over the years, in response to increased pumpage by industry, ground-water levels have declined until by 1972 the water level in state observation well PK-4 was 75 to 80 ft (23 to 24 m) below the land surface[2]. Pumpage in the general area now (1973) totals about 8 Mgal/d (3.03 x 10^4 m^3/d), of which 4.7 Mgal/d (1.8 x 10^4 m^3/d) is pumped by the Du Pont Co.; approximately 3 Mgal/d (1.14 x 10^4 m^3/d) is pumped by the Pittsburgh Plate Glass Co., whose plant is about 1 mi (1.6 km) east of Du Pont's, and most of the remainder by the Consumers Water Co., Circleville Plastics Co., and the Owens-Illinois Co.

The persistent decline in ground-water levels at the Du Pont plant by 1968 prompted company engineers to study the water supply. The engineers estimated that their well field had a maximum potential yield of 6.3 Mgal/d (2.4 x 10^4 m^3/d). By acquisition of property south of the plant and drilling of wells there, an additional supply of 3.6 Mgal/d (1.36 x 10^4 m^3/d) would become available. The engineers concluded that their problem was local and could be solved by spreading pumping over a larger area.

The Ohio Department of Natural Resources, Division of Water (now Geological Survey), recognized a need to study the water-supply situation in the entire area of industrial development and insofar as possible determine the total quantity of ground water available and conditions for its optimum development. Elsewhere in the Circleville area ground-water reservoirs capable of large-scale development also were to be studied. The results of the subsequent investigation, made in cooperation with the U.S. Geological Survey, are set forth in this report. The ground-water reservoir and its sources of replenishment are described, the effects of present pumpage on ground-water levels are assessed, and recharge rates and potential yield of the sand and gravel aquifer in the Circleville area are estimated.

[1]Conversion factors for the terms used in this report are listed below:

Multiply English unit	*by*	*to obtain metric unit*
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
million gallons (Mgal)	3785.4	cubic meters (m^3)
square feet per day (ft^2/d)	0.0929	square meters per day (m^2/d)
gallons per minute (gal/min)	0.06309	liters per second (l/s)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)

[2]Some recovery occurred in 1973, owing largely to above-average rainfall in the latter part of 1972, when evapotranspiration was near minimum (see fig. 3).

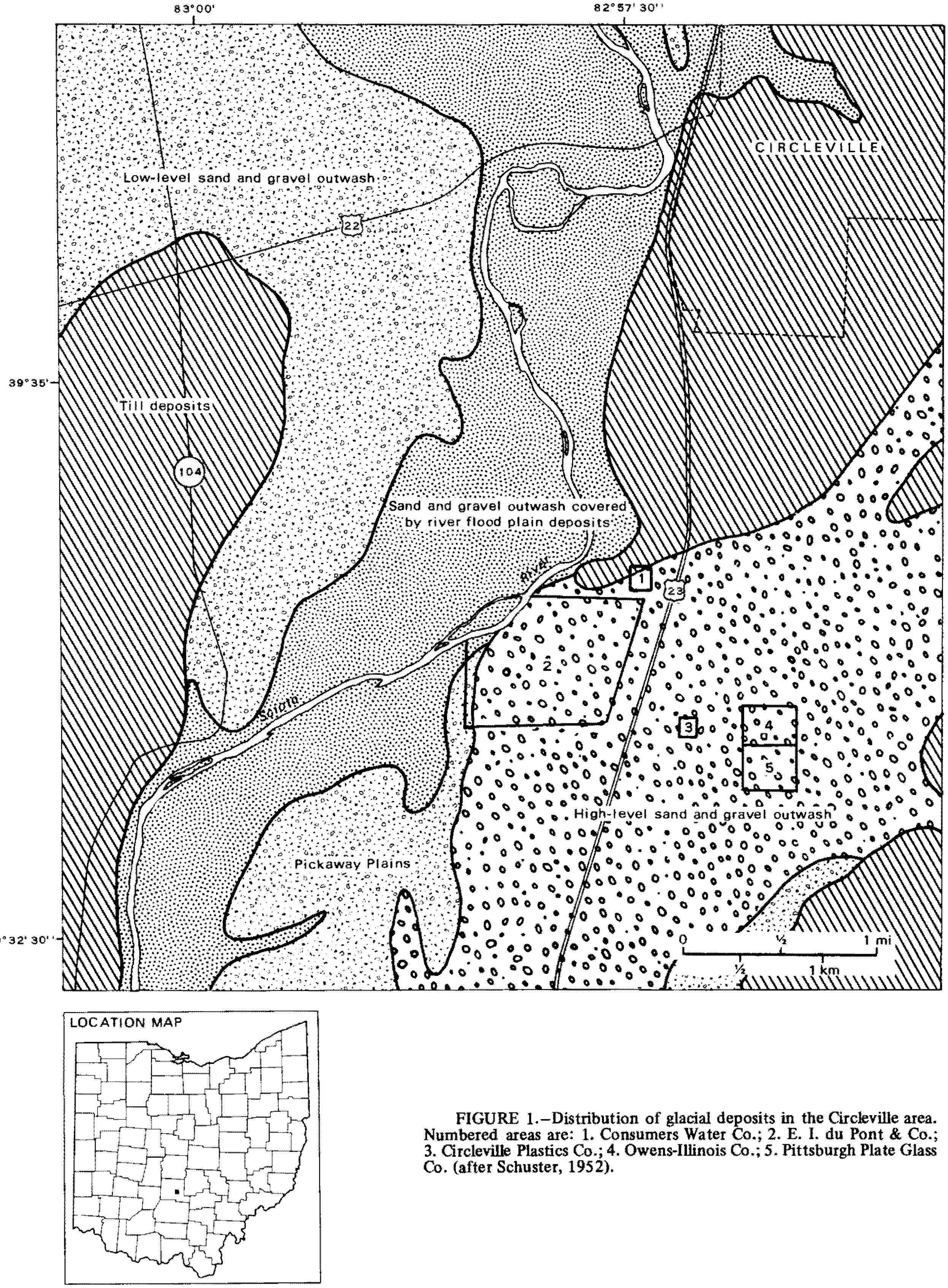


FIGURE 1.–Distribution of glacial deposits in the Circleville area. Numbered areas are: 1. Consumers Water Co.; 2. E. I. du Pont & Co.; 3. Circleville Plastics Co.; 4. Owens-Illinois Co.; 5. Pittsburgh Plate Glass Co. (after Schuster, 1952).

Thanks are extended to officials of E. I. du Pont de Nemours & Co. for making hydrologic data freely available and to officials of the city of Circleville, the Pittsburgh Plate Glass Co., the Owens-Illinois Co., the Consumers Water Co., and other concerns for their cooperation in this investigation.

The author acknowledges the work of R. E. Fidler, of the U.S. Geological Survey, who made a survey of wells, collected pumpage data, and supervised the drilling of four test holes by the Ohio Division of Water.

ORIGIN OF THE SAND AND GRAVEL DEPOSITS

Sand and gravel derived from the melting of continental glaciers underlie large parts of eastern Pickaway County in and adjacent to the Scioto River valley (fig. 1). Occurring in what once was a topographically low area developed by preglacial streams in relatively nonresistant shale bedrock, the sand and gravel deposits were laid down in two stages. The high-level outwash was deposited first, when the Scioto valley and its chief tributary valleys were partly filled by long tongues of glacial ice. Sediment-laden meltwaters, confined between these ice tongues and the bedrock uplands to the east, discharged their load of sand and gravel within an elongate area of approximately 8 mi^2 (21 km^2) lying approximately parallel to the Scioto River. The high-level deposits average 150 ft (46 m) in thickness and form a relatively flat terrace at a general altitude of 700 to 710 ft (213 to 216 m) above sea level in most of the heavily pumped area.

The ice tongues eventually melted from the main valleys, and these valleys became the chief repositories for the sand and gravel being washed from the dwindling ice. During this final melting stage the bulk of the outwash or valley-train deposits in the Scioto valley was laid down. These low-level deposits extend nearly the full length of the valley, being especially prominent between Columbus and the mouth of the Scioto River at Portsmouth. In the Circleville area the low-level deposits form extensive plains, called the lower terrace, on both sides of the Scioto River flood plain. Pickaway Plains, an area of approximately 2 mi^2 (5 km^2) on the east side of the Scioto River and centering about 4 mi (10 km) southwest of Circleville, is representative of the low-level deposits and is at an altitude of 655 to 660 ft (200 to 201 m).

In the postglacial interval, estimated to have begun 15,000 to 18,000 years ago, the Scioto River established its present course and cut its flood plain—1 mi (1.6 km) wide in places—20 to 30 ft (6 to 9 m) into the low-level deposits in the Circleville area. On the flood plain the sand and gravel deposits are generally covered by alluvium, 5 to 15 ft (2 to 5 m) thick and consisting of clay, silt, and sand laid down by the modern stream during overflow (see fig. 1).

The high-level and low-level sand and gravel deposits are contiguous in the Circleville area, combining to form a single extensive ground-water reservoir, which ranges in thickness from about 40 ft (12 m) in places beneath the flood plain to about 225 ft (69 m) in upland areas locally underlain by relatively deep bedrock valleys.

Drillers' logs of wells show that the sand and gravel deposits are interbedded locally with deposits of clay and till. Till, which is commonly reported on the logs either as clay, clay and boulders, or hardpan, is an unsorted, poorly permeable residue of soil and rock fragments dropped in place when the ice melted. The presence of till, especially where it is fairly widespread, shows that deposition of the outwash was interrupted at least once by a local readvance of the glacier; the ice overrode meltwater deposits previously laid down. Till generally underlies the uplands, including most of the city of Circleville, in areas adjacent to the Scioto River valley (see fig. 1).

Interbedded clay and till deposits are sufficiently widespread in places to function hydraulically as a semiconfining bed, separating the sand and gravel into an upper and a lower aquifer. Where this occurs, the water level in shallow wells may be different than the water level in nearby deeper wells. Representative wells in the Circleville area are listed in table 1, which gives their depth, yield, and construction features. The wells are identified by number and location in figure 2, which also shows contours on the bedrock surface. Drillers' logs are shown in graphic form in figure 3.

THE GROUND-WATER RESERVOIR IN THE VICINITY OF THE PUMPING CENTERS

DESCRIPTION

Wells drilled for industrial water supply in the study area range in depth from about 60 to 180 ft (18 to 55 m) (table 1, wells 38 to 49 and 66 to 68). Commonly the lowest 10 to 40 ft (3 to 12 m) of the wells is screened and open to the aquifer. Yields of individual wells typically range from 500 to 1,000 gal/min (32 to 63 l/s); specific capacities range from 10 to 100 (gal/min)/ft of drawdown (2 to 21 (l/s)/m), but the usual range is 15 to 50 (gal/min)/ft (3 to 10 (l/s)/m)[3].

At the Pittsburgh Plate Glass Co. plant, till deposits, reported on most drillers' logs between 50 and 85 ft (15 and 26 m) below the suface, are interbedded with the sand and gravel deposits. The till evidently acts as a semiconfining bed. On August 6, 1973, the water level measured in a small-diameter drive-point well, 45 ft (14 m) deep, open above the till layer, was 28 ft (9 m) below land surface. A few tens of feet away the nonpumping water level in one of Pittsburgh Plate Glass Co.'s supply wells, 135 ft (41 m) deep and screened below the till layer, was 52 ft (16 m) below land surface, a difference in water levels of 24 ft (7 m).

Pumping has exaggerated the difference between water levels in the aquifers. Records of wells drilled at the Pittsburgh Plate Glass plant in 1962, before pumping started, show that the water level in a shallow well, 63 ft (19 m) deep, was 22 ft (7 m) below land surface, while the water level in a nearby well 135 ft (41 m) deep was 29 ft (9 m) below the surface, a difference in water levels of only 7 ft (2 m).

No data were available elsewhere in the study area to show the effect of interbedded till or clay layers on the aquifer system. At the Du Pont plant, drillers' logs and geophysical logs indicate till or clay at various depths in the sand and gravel sequence, most commonly between 20 and 60 ft (6 and 18 m) below the surface. As at the Pittsburgh

[3]Typically, well efficiencies began to decline after a year or two of pumping because of chemical incrustation of the well screens. Engineers at the Du Pont Co. schedule chemical cleaning of production wells at 1- to 2-year intervals to maintain efficiencies.

TABLE 1.–*Records of wells in the Circleville area, Ohio*[1]

Map no.	Owner's no.	Owner or name	Altitude at well (ft above sea level)	Depth of well (ft)	Diameter of well (in)	Depth to bedrock (ft)	Principal aquifer: Character of material	Principal aquifer: Thickness (ft)	Principal aquifer: Depth (ft)	Yield (gal/min)	Water level: Below land surface (ft)	Water level: Date	Use	Remarks
1		Richard Watt	676	64	5.5		S & G	6	64	11	5	5-31-66	D	
2		Bruce Stevenson	672	88	4		S & G	68	88	15	10	7-27-64	D	
3	6-TD-2	State of Ohio	671	130		114	S & G						T	
4		W. Dunn	685	118	5		S & G	6	118	20	14	11-7-62	D	
5	6-TD-3	State of Ohio	665	90		82	S & G						T	
6		Howard Thomas	667	31	6		S & G	10	31	5	20	1955	D	
7		G. Edelblute	666	72	4	68	S & G	7	68	9	22	11-29-57	D	
8		Lincoln Plastics Co.	706	75	10		S & G	25	75		44	1955	I	
9		P. Adkins	690	52	5		S & G	3	52	18	20	8-17-66	D	
10		P. Adkins	700	50	6		S & G	3	50	20	35	11-29-54	D	
11	6-1a-1	State of Ohio	655	103			S & G				2	4-71	T	
12		E. Richards	675	30	4		S & G	4	30	15	20	7-1-59	D	
13		R. Burris	660	46	5		S & G	6	46	25	20	11-22-66	D	
14		Homer Logan	690	80	4		S & G	7	80	10	35	11-4-52	D	
15		W. Ferrell	695	113	4		S & G	15	113	12	42	8-22-53	D	
16		M. C. List	695	54	6		S & G	7	45	20	38	12-8-54	D	
17		M. C. List	692	59	4		S & G	2	59	20	30	4-23-59	D	
18		W. Hoffman, Jr.	684	62	6		S & G	23	62		30	9-55	D	
19		J. Stevenson	670	43	6		S & G	8	43		15	10-56	D	
20	6-1a-2	State of Ohio	667	132		129	S & G				13	4-71	T	
21		W. Richards	660	32	8.5		S & G	6	32	60	11	6-21-65	D	
22	PK-41	State of Ohio	675	155	6		S & G				17	8-8-73	T	Gamma log on file
23		Consumers Water Co.	705	130	8		S & G	10	123	180	49	8-16-73	P	
24		Columbus and Southern Ohio Electric Co.	705	81	4		S & G	31	81		45	1954	I	
25	8-TD-1	State of Ohio	700	190		185	S & G						T	
26		Robert Carpenter	705	79	4		S & G	5	79	13	25	8-12-57	D	
27		A. E. Pusey	702	135	4		S & G	25	90	15	32	1963	D	
28	PK-39	State of Ohio	710	130	6		S & G				23	8-8-73	T	Gamma log on file
29	8-TD-2	State of Ohio	710	170		169	S & G						T	
30	8-TD-3	State of Ohio	712	230		228	S & G				20		T	
31	7-TD-1	State of Ohio	677	147		142	S & G						T	
32		W. J. Barthelmas	665	64	4		S & G	5	64	3	44	8-27-59	D	
33	7-TD-2	State of Ohio	667	155		146	S & G						T	
34	7-TD-3	State of Ohio	651	135		129	S & G						T	
35	PK-40	State of Ohio	660	62	6		S & G	3	62		13	8-8-73	T	Gamma log on file
36		W. W. Walton	685	86	6		S & G	6	86	20	34	10-24-61	D	
37		C. Bowers	695	60	4		S & G	8	60	18	25	2-56	D	
38	213	E. I. du Pont & Co.	698	149	8	145	S & G	40	140		48	4-5-68	T	Gamma log on file
39	212	E. I. du Pont & Co.	700	154	8	154	S & G	70	150		50	4-5-68	T	Gamma log on file
40	204	E. I. du Pont & Co.	650	67			S & G	47	67		6	6-51	T	Abandoned

41	203	E. I. du Pont & Co.	650	84		78	S & G	45	78		9	6-51	T	Abandoned
42	202	E. I. du Pont & Co.	660	53		50	S & G	30	50		19	6-51	T	
43	PW-2	E. I. du Pont & Co.	695	117	16		S & G	20	117	500	36	8-4-53	I	Depth to water 94 ft in nearby well, 8-8-73
44	PW-6	E. I. du Pont & Co.	704	173	16	171	S & G	64	171	1000	54	5-20-56	I	Depth to water 90 ft in nearby well, 8-8-73
45	PW-7	E. I. du Pont & Co.	700	127	8	117	S & G	24	117	500	65	9-29-66	I	Depth to water 80 ft in nearby well, 8-8-73
46	PW-3	E. I. du Pont & Co.	703	146		144	S & G	29	144	1000	42	11-57	I	Depth to water 78 ft in nearby well, 8-8-73
47	PW-4	E. I. du Pont & Co.	704	166	16		S & G	40	166	800	47	6-25-59	I	Depth to water 93 ft in nearby well, 8-8-73
48	206	E. I. du Pont & Co.	706	140	6		S & G	31	136		74	8-16-73	T	State observation well PK-4
49	PW-5	E. I. du Pont & Co.	704	176	16	175	S & G	22	175	800	47	12-7-60	I	Depth to water 95 ft in nearby well, 8-8-73
50	PK-7	State of Ohio	705	172	6		S & G	8	172		48	8-8-73	T	Gamma log on file
51		R. B. Anderson	710	82	5		S & G	12	82	40	12	6-68	D	
52		Timmins	705	118	4		S & G	2	118	9	25	1-55	D	
53		R. Simkins	697	250	5	100	Sh	150	250	1.5	78	7-15-68	D	
54	6-1b-5	State of Ohio	657	116			S & G				11	4-71	T	
55		C. Adams	665	47	6		S & G	17	47		34	8-54	D	
56	6-1b-4	State of Ohio	657	96		95	S & G				13	4-71	T	
57	9-TD-1	State of Ohio	656	95		92	S & G						T	
58	9-TD-2	State of Ohio	655	132		132	S & G						T	
59	9-TD-4	State of Ohio	685	192		190	S & G						T	
60		S. Dearth	702	60	4		S & G	2	60		30	5-53	D	
61		Deffenbaugh	702	62	4		S & G	20	60		21	5-54	D	
62	TH W-1	Columbus and Southern Ohio Electric Co.	700	163	8	162	S & G	42	161		37	8-8-73	T	
63	TH E-1	Columbus and Southern Ohio Electric Co.	702	147			S & G	48	147		37	4-7-69	T	
64		J. P. Noecker	734	122	4		S & G	77	122		19	5-55	D	
65		American Legion	645	66	5		S & G	20	66		38	7-61	P	
66	No. 3	Pittsburgh Plate Glass Co.	703	134	20		S & G	26	134	1500	42	8-6-66	I	Depth to water 52 ft in well No. 1, 8-16-73
67	No. 1	Owens-Illinois Co.	702	139	12		S & G	35	139	400	46	8-16-73	I	
68		Circleville Plastics Co.	705	96	8		S & G	13	96	100	58	1-2-70	I	
69		D. E. Goodchild, Inc.	680	68	6		S & G	8	68	30	36	8-8-73	I	

[1]Explanation of terms and symbols:

Map no.: The number of the well shown on figure 2.
Owner or name: The name of the landowner or tenant at the time the well was drilled or at the time of the well inventory.
Altitude at well: Determined approximately from the topographic maps of the U.S. Geological Survey.
Depth of well: Depth reported by driller, owner, or tenant.
Depth to bedrock: Depth to the surface of the consolidated rocks.
Character of material: Geological material in which water was obtained or in which well was terminated: G, gravel; S, sand; Sh, shale.
Yield: The rate at which the well was pumped or bailed.
Water level: The depth below land surface of the water level in the well as reported or measured.
Date: Date of determination of the water level.
Use: D, domestic supply; I, industrial use; P, public supply; T, test well.

Plate Glass plant, these till deposits probably act as a semiconfining bed, but there are no shallow wells in the Du Pont plant area to reveal the possible presence of a relatively shallow water table above the potentiometric surface[4] in the deeper wells.

In the gross functioning of the hydrologic system it is not critically important whether the sand and gravel deposits are separated by a semiconfining bed. Although a semiconfining bed may retard the vertical movement of ground water, it cannot prevent the interchange of water between the upper and lower parts of the sand and gravel reservoir. Water will move through the semiconfining bed in response to head differences in the respective aquifers. Where the water level in shallow wells is above that in relatively deep wells, as in the area of the Pittsburgh Plate Glass plant, water

[4] The potentiometric surface is an imaginary surface connecting points to which water would rise in tightly cased wells (see Lohman, 1972, p. 8).

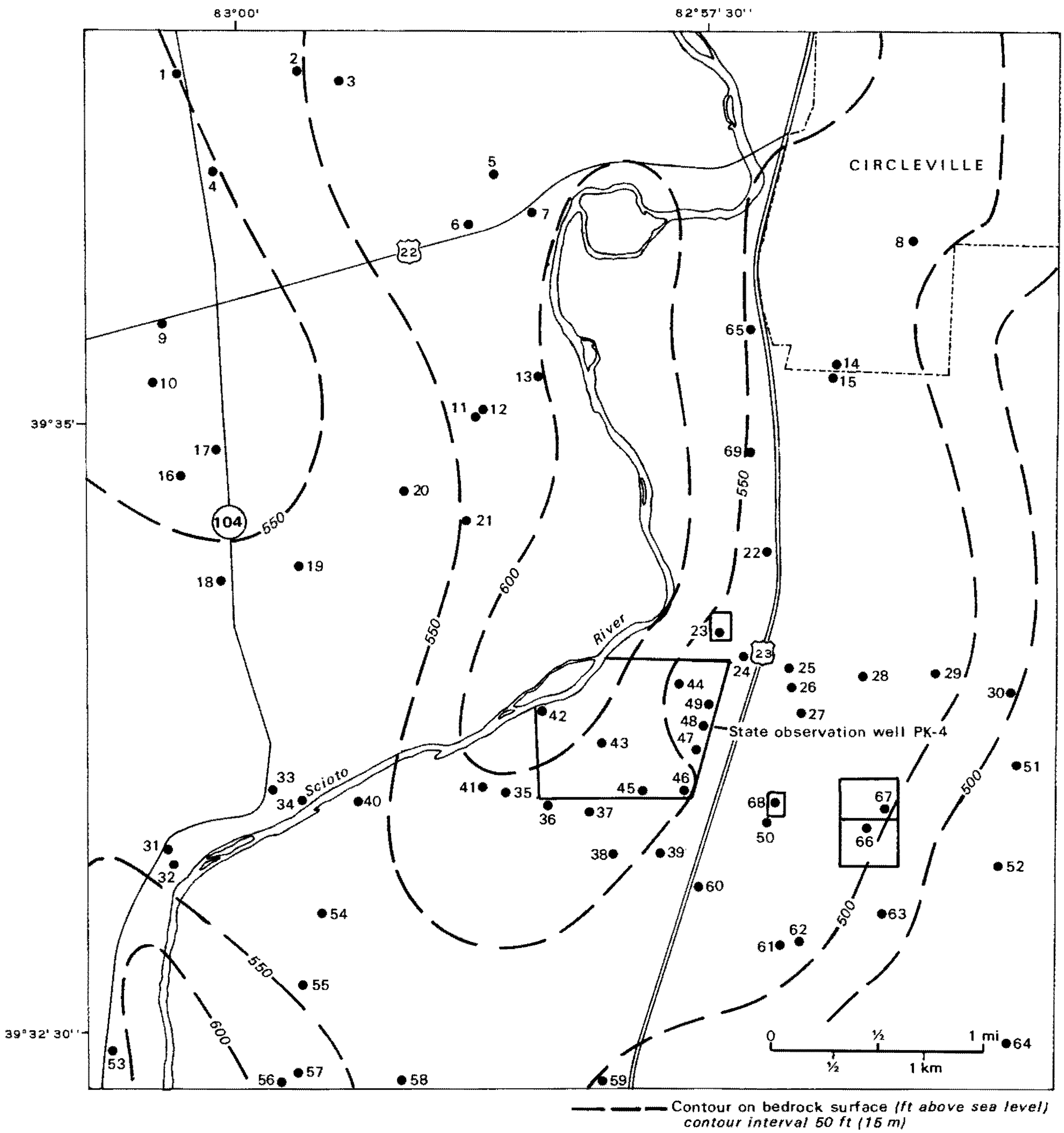


FIGURE 2.–Locations and identifying numbers of selected wells listed in table 1. See table 1 for plant identifications.

will move from the upper to the lower part of the formation. Where the relative positions of the water levels are reversed, water will move in the reverse direction, from the lower to the upper part of the formation.

Ground-water levels fluctuate in response to variation in rainfall, use of water by plants, changes in pumping rates, and other factors. The water table generally is highest in the spring before evapotranspiration peaks and lowest in the fall before the end of the growing season. In observation well PK-4 (see fig. 5) seasonal fluctuations over the past several years have ranged from as little as 4 or 5 ft (1 to 2 m) to as much as 8 ft (2 m).

When a well is pumped, water levels are drawn down in the vicinity of the well and a cone of depression is formed. The size and shape of this cone are determined by the hydraulic properties of the aquifer, pumpage and its distribution, and amount and distribution of recharge. When pumpage and recharge are balanced, the cone of depression will eventually stabilize. If pumpage continues to increase, the cone of depression will likewise expand until enough water is diverted to the well to meet the demand. If recharge is less than pumpage, ground-water levels will continue to decline as water is removed from storage until critical levels are reached, necessitating a reduction in pumpage.

Contours on the potentiometric surface in the area influenced by pumping at the Du Pont Co. and other nearby industrial plants are shown in figure 4. Evidence that the cone has been spreading and deepening over the years is the decline of the water level in observation well PK-4 (fig. 5), at the east edge of the Du Pont property. The hydrograph shows a persistent, long-term decline from 1960, when the record began, to the present. In 1973 there was a minor recovery in ground-water levels owing to above-average rainfall in the fall of 1972, when evapotranspiration was at a minimum. Also shown in figure 5 is a graph of pumpage at the Du Pont plant; pumpage increased from an average of 3.6 Mgal/d (1.36 x 10^4 m^3/d) in 1966 to 4.7 Mgal/d (1.78 x 10^4 m^3/d) by 1971.

SOURCES OF REPLENISHMENT

The principal source of recharge to the aquifer supplying the industrial wells is precipitation. Some precipitation enters the aquifer within the area underlain by the cone of depression, but most enters upgradient from the cone and flows into it in response to the regional gradient. Generally the potentiometric surface in the Circleville area is higher in upland areas. Consequently, ground water moves from the uplands toward the Scioto River valley. This component of recharge, moving in response to the regional gradient, is referred to here as underflow.

Where the sand and gravel deposits are separated by a semiconfining bed, water from precipitation reaches the wells after moving downward through the semiconfining bed. Or, water may enter the lower aquifer directly in areas where the semiconfining bed is absent and move laterally beneath the semiconfining bed. Water also enters the aquifer from the Scioto River by influent seepage where the water table is below the stream, as in the area of the Du Pont plant. Infiltration is relatively low here because the wells are at some distance from the river, and the ground-water gradient between the wells and the river is low. Infiltration will become increasingly important as the cone of depression becomes deeper and wider in response to increased pumping.

The dashed contours in figure 4 show the potentiometric surface as it was assumed to be before large-scale pumping. The difference in altitude between the dashed contours and the present contours represents the net drawdown, in feet, and is the basis for figure 6, which shows the decline of the potentiometric surface since pumping began. The area enclosed by the zero change line is approximately 5 mi^2 (13 km^2). The volume of unwatered material, determined by calculation, is approximately 2 billion ft^3 (5.2 x 10^6 m^3); if this material was 20 percent saturated originally, nearly 3 billion gal (1.13 x 10^7 m^3) of water has been removed from storage since pumping began. Three billion gal (1.13 x 10^7 m^3) of water is enough to meet the present demand of about 8 Mgal/d (3.03 x 10^4 m^3/d) for 375 days. If the 3 billion gal (1.13 x 10^7 m^3) is prorated over the entire 17-year period since pumping began, it is equivalent to 0.48 Mgal/d (1.8 x 10^3 m^3/d).

The rate of growth of the cone of depression has not been constant. The record of well PK-4, which shows a net decline in water level of about 30 ft (9 m) between 1960 and 1973, indicates that the cone has grown rapidly since about 1963, shortly after pumping began at the Pittsburgh Plate Glass plant. If the entire cone had developed the past 10 years the total amount of water removed from storage, 3 billion gal (1.13 x 10^7 m^3), would correspond to an average rate of withdrawal of 0.8 Mgal/d (3.03 x 10^3 m^3/d). The overall rate must be less than this, however, because the cone began to develop the moment pumping began. For purposes of the analysis which follows, assume that the cone is growing at a rate consequent upon the removal of approximately 0.7 Mgal/d (2.6 x 10^3 m^3/d) from ground-water storage. This is equivalent to about 3 in (76 mm) of water annually for the 5-mi^2 (13-km^2) area of the cone of depression.

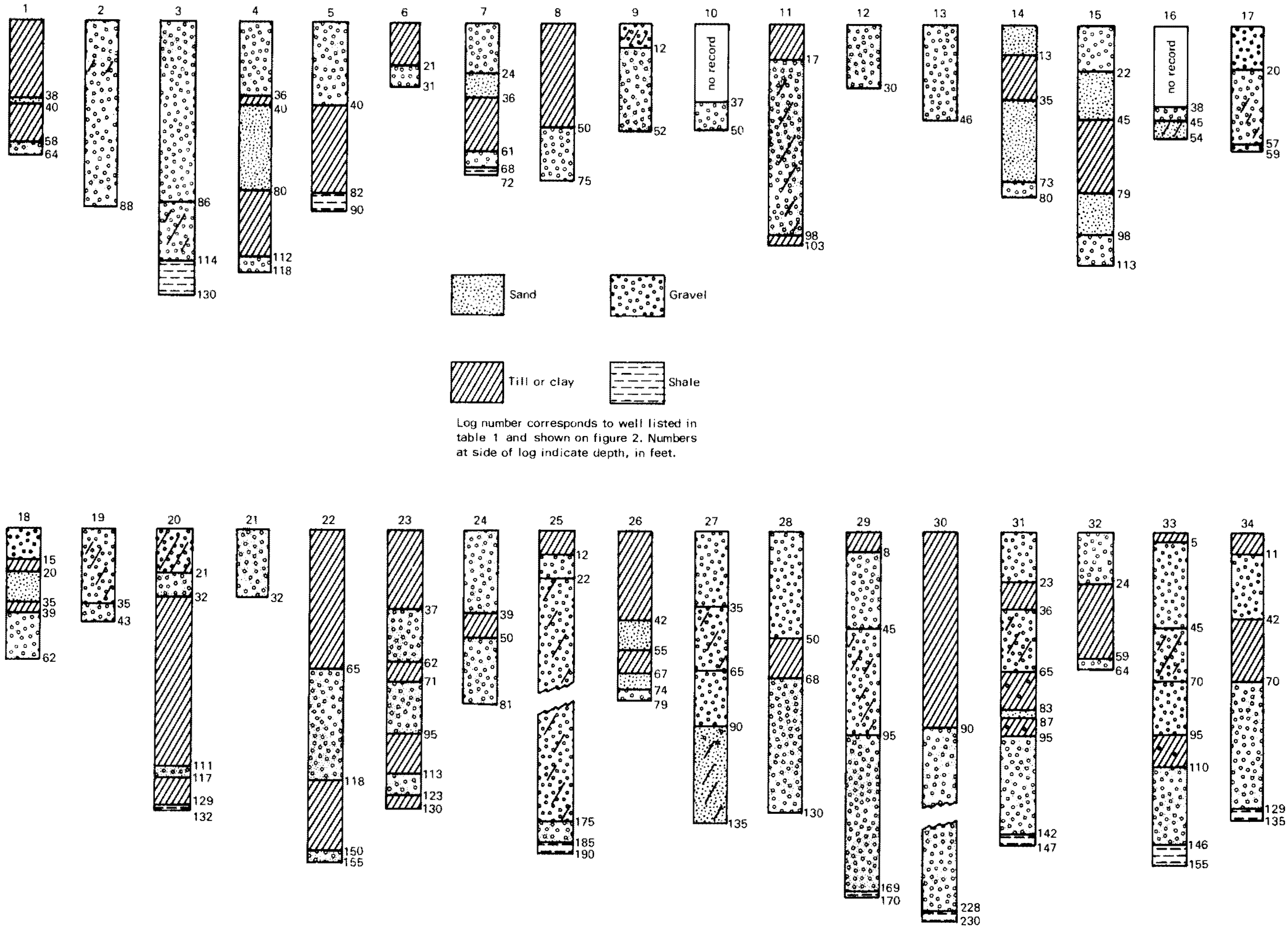
RECHARGE COMPONENTS

The transmissivity of the aquifer was determined from an analysis of the water-level-decline map (fig. 6). The transmissivity (formerly the coefficient of transmissibility, a term originally defined by Theis, 1935), is the product of the hydraulic conductivity (formerly the coefficient of permeability) of an aquifer and its saturated thickness. The field coefficient of permeability is defined (Ferris and others, 1962, p. 72) as the rate of flow, at prevailing temperature, in gallons per day, through a cross-sectional area of 1 ft^2 under a hydraulic gradient of unity[5]. Using pairs of contours located close to the respective pumping centers, where accretion from infiltration of precipitation is considered negligible, the transmissivity was calculated from the following relationship:

$$T = \frac{2Q}{(L_1 + L_2)\frac{\Delta h}{\Delta r}}$$

where T = transmissivity (ft^2/d), Q = quantity of water being pumped (ft^3/d), L = length of closed contour (ft), $(L_1 + L_2)/2$ = average length of two adjacent contours (ft), Δh = contour interval (ft), and Δr = average distance between the two adjacent contours (ft).

[5]For a definition of the preferred term, hydraulic conductivity, see Lohman (1972, p. 6).



Log number corresponds to well listed in table 1 and shown on figure 2. Numbers at side of log indicate depth, in feet.

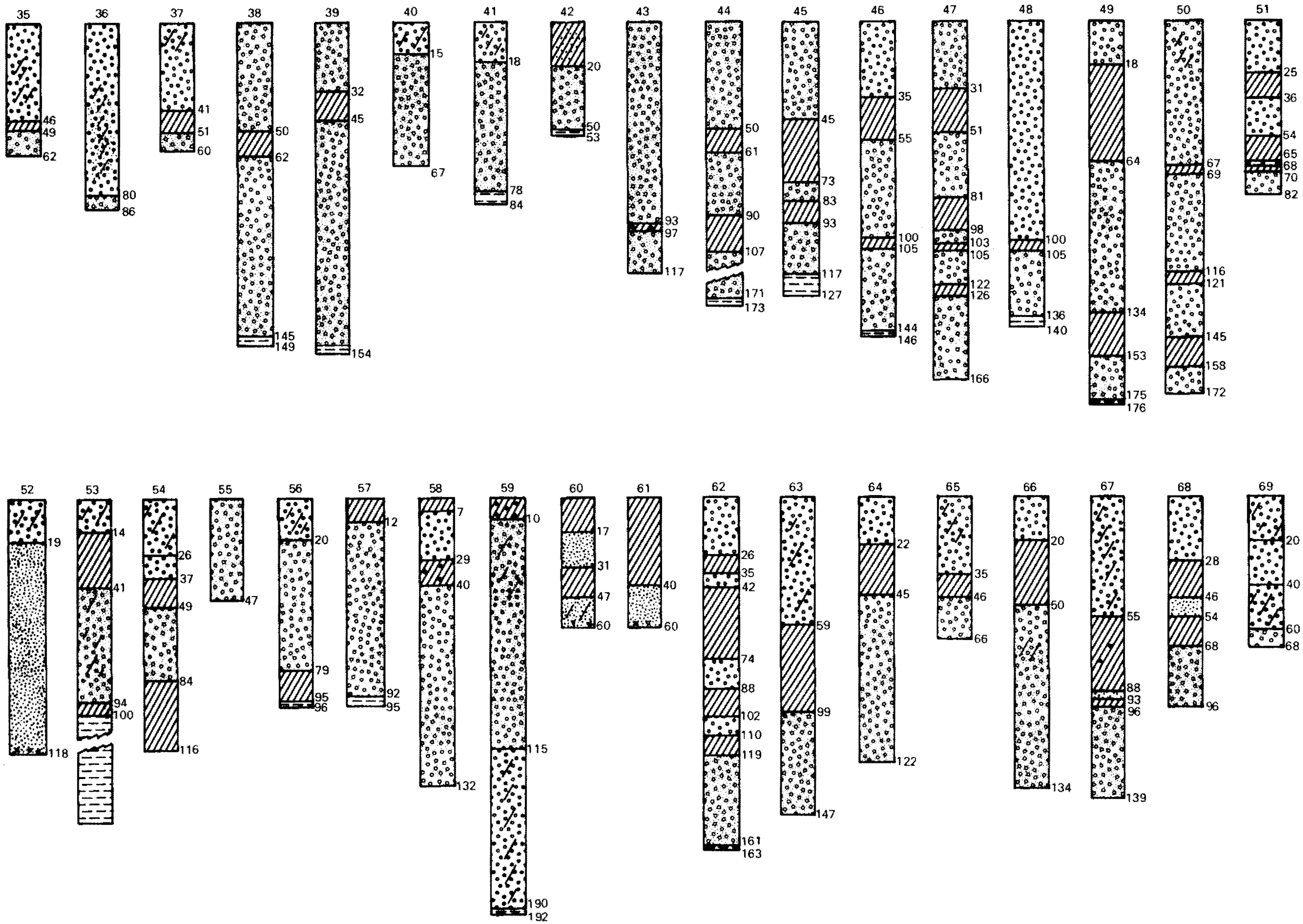


FIGURE 3.–Graphic logs of wells in the Circleville area.

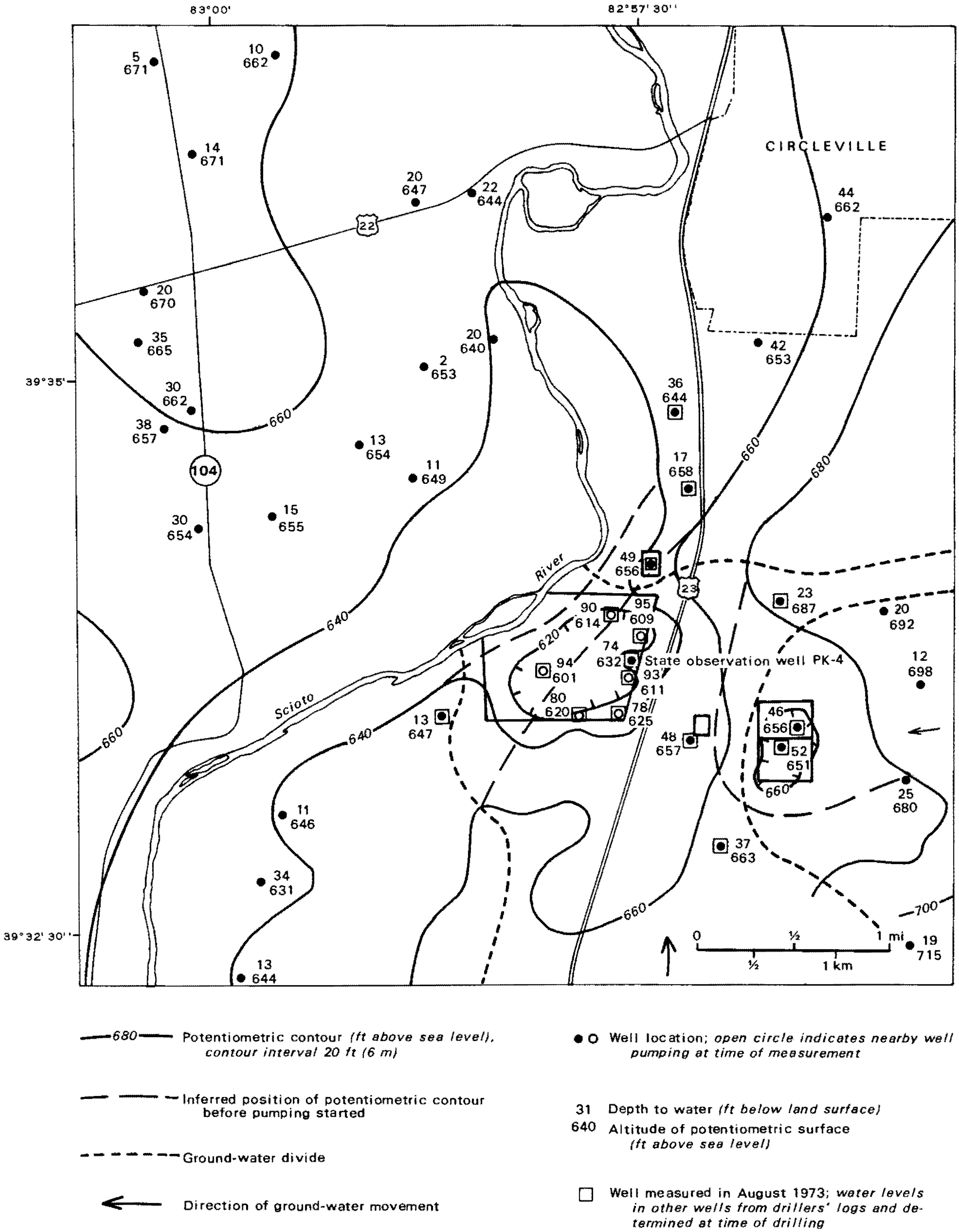


FIGURE 4.–Potentiometric surface in the Circleville area. See figure 1 for plant identification.

Using the 40- and 50-ft (12- and 15-m) contours in the Du Pont area and the 20- and 30-ft (6- and 9-m) contours in the Pittsburgh Plate Glass-Owens-Illinois area, the results for the Du Pont area are:

$$T = \frac{2 \times 6.4 \times 10^5 \text{ ft}^3/\text{d} \times 500 \text{ ft}}{(10{,}700 \text{ ft} + 7{,}200 \text{ ft}) \times 10 \text{ ft}} = 3{,}575 \text{ ft}^2/\text{d} \ (332 \text{ m}^2/\text{d})$$

and for the Pittsburgh Plate Glass-Owens-Illinois area are:

$$T = \frac{2 \times 4.27 \times 10^5 \text{ ft}^3/\text{d} \times 1{,}100 \text{ ft}}{(11{,}200 \text{ ft} + 4{,}200 \text{ ft}) \times 10 \text{ ft}} = 6{,}100 \text{ ft}^2/\text{d} \ (567 \text{ m}^2/\text{d}).$$

The relatively low transmissivity value determined for the Du Pont area is partly the result of the reduction, caused

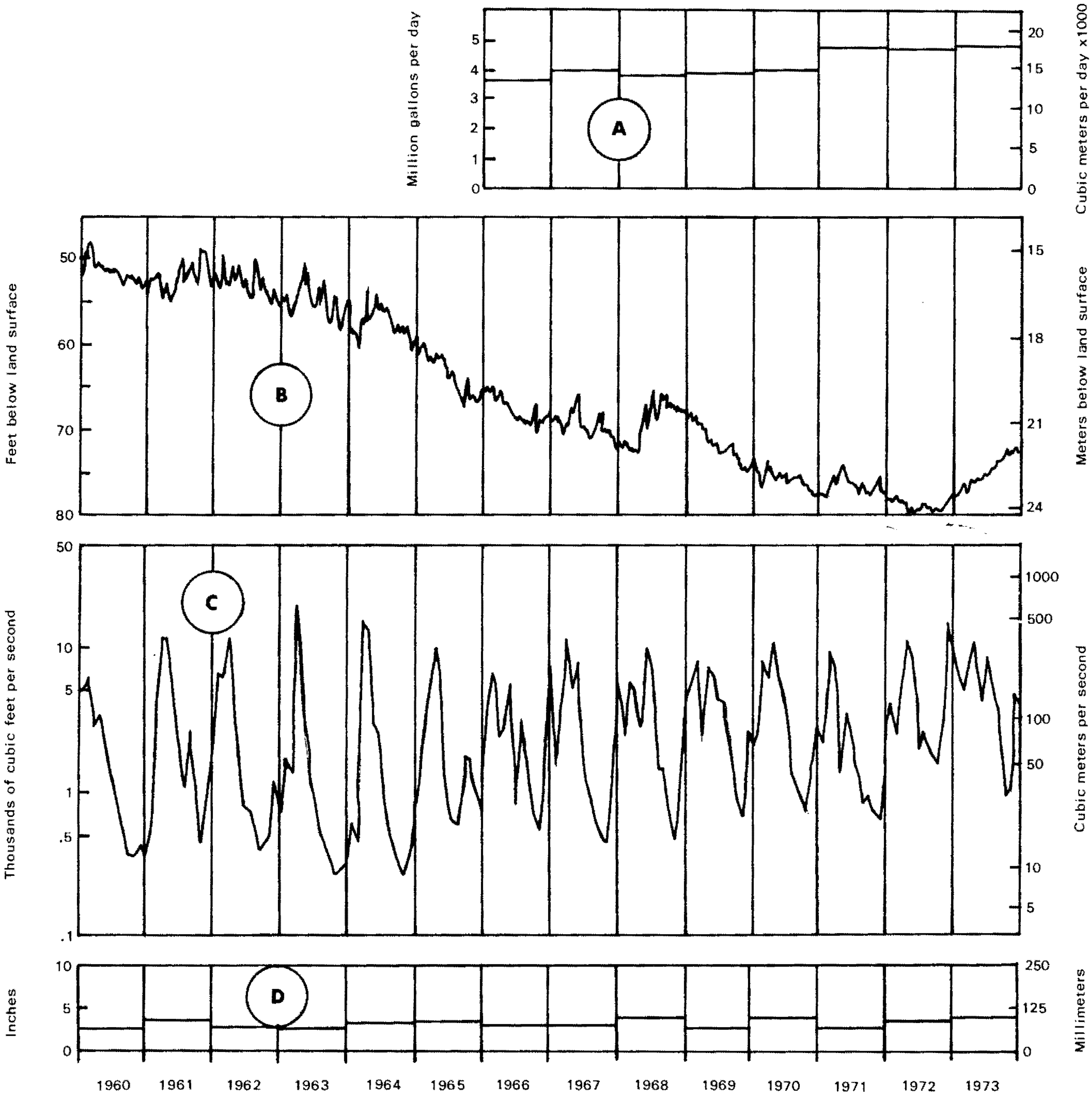


FIGURE 5.—Graphs of *A*, average pumpage at the Du Pont plant; *B*, water level in observation well PK-4; *C*, flow in the Scioto River at Chillicothe; *D*, mean monthly precipitation at Circleville.

by pumping, in the saturated thickness of the aquifer. The saturated thickness is estimated at about 60 ft (18 m) in the Du Pont area, compared with about 100 ft (30 m) in the Pittsburgh Plate Glass area. When these saturated thickness values are divided into the respective transmissivity values for each site, to determine the hydraulic conductivity of the sand and gravel aquifer, the results[6] are essentially the same, 60 ft/d (18 m/d), for the Du Pont area and 61 ft/d (19 m/d) for the Pittsburgh Plate Glass area. These values apply to the aquifer as a whole, which includes a certain amount of poorly permeable clay and till. The hydraulic conductivity, or permeability, of the sand and gravel layers within the aquifer is undoubtedly much higher. A common range in hydraulic conductivity values for sand and gravel deposits generally in Ohio is 265 to 535 ft/d (80 to 163 m/d). In the Scioto valley at Piketon, about 40 mi (64 km) south of Circleville, where the U.S. Atomic Energy Commission made tests of the outwash deposits in 1963 and 1965, the hydraulic conductivity at closely spaced sites ranges from

[6] To convert feet per day to gallons per day per square foot multiply by 7.48.

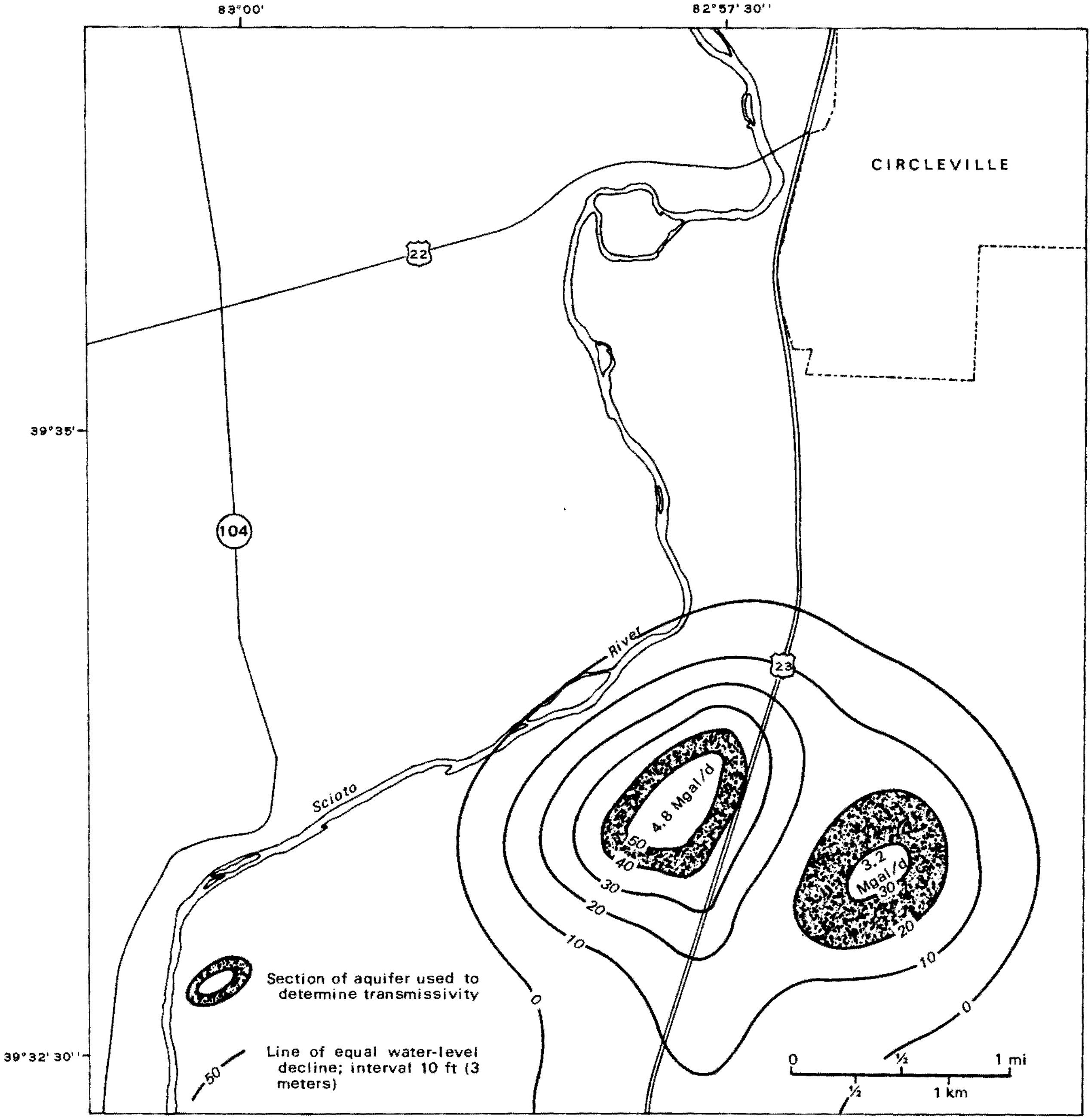


FIGURE 6.—Decline in the potentiometric surface in the vicinity of the industrial wells since pumping began. Pumpage figures are shown for principal pumping centers.

382 to 450 ft/d (116 to 137 m/d) (Norris and Fidler, 1969, p. 61). The low-level deposits underlying the flood plain at Circleville are generically equivalent to the outwash deposits at Piketon and very likely compare with them in hydraulic characteristics. The low-level deposits are far better ground-water sources than the high-level deposits because of their proximity to the Scioto River and consequent infiltration possibilities. Locally, the deposits may not be suitable for large-scale ground-water development. Test drilling and aquifer tests may be necessary to locate and evaluate the more favorable sites.

As stated earlier, the chief source of recharge to the pumped wells at Du Pont and Pittsburgh Plate Glass is underflow. Underflow is the product of the transmissivity of the aquifer, the width of the section through which flow occurs, and the hydraulic gradient. The potentiometric map (fig. 4) shows that much of the underflow that reaches the Du Pont well-field area moves from southeast to northwest, toward the Scioto River. The width-of-flow section near the east margin of the plant property is approximately 10,500 ft (3,200 m). The hydraulic gradient is estimated at 0.008 ft/ft (0.008 m/m). The product of these values multiplied by the transmissivity, 3,575 ft^2 (332 m^2/d), yields 3.0 x 10^5 ft^3/day or 2.2 Mgal/d (8.3 x 10^3 m^3/d), for underflow. This amounts to 47 percent of the water pumped by the Du Pont Co.

Another component of recharge to the aquifer tapped by the Du Pont wells is induced infiltration from the Scioto River. Over the years, pumping levels have steadily declined and currently, at altitudes ranging from 605 to 625 ft (184 to 190 m), are below the river altitude of 638 ft (194 m) in the plant area. The length of the losing reach, and the section through which infiltration from the river occurs, is approximately 5,000 ft (1,524 m). The average ground-water gradient between the river and the plant wells is estimated to be 0.0066 ft/ft (0.0066 m/m). The product of the gradient, the width-of-flow section, and the transmissivity is 0.9 Mgal/d (3.4 x 10^3 m^3/d), or 19 percent of Du Pont's pumpage.

If 47 percent of Du Pont's pumpage is derived from regional underflow and 19 percent infiltrates from the Scioto River, the remainder, 34 percent, or approximately 1.6 Mgal/d (6.0 x 10^3 m^3/d), must come from other sources. The equivalent of approximately 3 in (76 mm) annually is being taken from ground-water storage, as noted previously. For the 3.7-mi^2 (9.6-km^2) area of influence of Du Pont's wells (determined from fig. 6) this is equivalent to 0.5 Mgal/d (1.9 x 10^3 m^3/d). This leaves about 1.1 Mgal/d (4.2 x 10^3 m^3/d) to be accounted for from infiltration of direct precipitation on the area underlain by the cone of depression. This recharge moves vertically to the wells, a somewhat arbitrary distinction over recharge entering the ground upgradient from the cone and moving laterally to the wells as underflow.

For an area of 3.7 mi^2 (9.6 km^2) to yield 1.1 Mgal/d (4.2 x 10^3 m^3/d) from direct precipitation, about 6.2 in (157 mm) of water is required annually. This figure, approximately 16 percent of the average annual precipitation recorded at Circleville from 1960 to 1974, is consistent with infiltration rates determined at other sites in Ohio.

Values of the recharge components were determined also for the area of the Pittsburgh Plate Glass and Owens-Illinois plants. The plants together use approximately 3.2 Mgal/d (1.2 x 10^4 m^3/d) of water. Pumpage is sustained chiefly by regional underflow plus direct precipitation in the area underlain by the cone of depression. Some water is being taken from aquifer storage. Under pumping conditions, a ground-water divide exists between the Pittsburgh Plate Glass and Owens-Illinois wells and those of the Du Pont Co. No water from induced infiltration reaches the Pittsburgh Plate Glass and Owens-Illinois area nor does water move across the ground-water divide from this pumping center to that of the Du Pont area.

On the basis of the water-level-decline map (fig. 6) and the potentiometric map (fig. 4) it can be determined that ground water moves generally westward to the Pittsburgh Plate Glass and Owens-Illinois wells. The width of the section through which flow occurs is approximately 8,000 ft (2,438 m), and the hydraulic gradient is estimated to be 0.007 ft/ft (0.007 m/m). The product of these values multiplied by the transmissivity, 6,100 ft^2/d (567 m^2/d), yields 3.4 x 10^5 ft^3/d, or 2.6 Mgal/d (9.8 x 10^3 m^3/d), equivalent to about 80 percent of the water pumped. The remainder of the pumpage, 0.6 Mgal/d (2.3 x 10^3 m^3/d), is derived from direct precipitation on the area underlain by the cone of depression plus water removed from storage in the aquifer. The area of influence of the Pittsburgh Plate Glass and Owens-Illinois wells is determined from the water-level-decline map (fig. 6) as approximately 1.38 mi^2 (3.57 km^2). For this area to yield 0.6 Mgal/d (2.3 x 10^3 m^3/d) requires 9 in (228 mm) of precipitation annually. Assuming that the equivalent of 3 in (76 mm) annually comes from reduction in aquifer storage, the increment derived from direct precipitation is 6 in (152 mm) annually, about the same rate as determined previously for the Du Pont area. The results are summarized as follows:

Recharge component	Du Pont area		Pittsburgh Plate Glass and Owens-Illinois area	
	Mgal/d	m^3/d	Mgal/d	m^3/d
Underflow	2.2	8.3 x 10^3	2.6	9.8 x 10^3
River infiltration	0.9	3.4 x 10^3	0	
Direct precipitation (6 in annually)	1.1	4.2 x 10^3	0.4	1.5 x 10^3
Aquifer depletion (3 in annually)	0.5	1.9 x 10^3	0.2	7.6 x 10^2
Total	4.7	1.8 x 10^4	3.2	1.2 x 10^4

DISCUSSION

If pumping continues to increase at or in proximity to the Du Pont and Pittsburgh Plate Glass plants, ground-water levels will likewise continue to decline, though at a decreasing rate, as proportionately more water is derived from induced infiltration from the Scioto River. Ultimately, if the water-level decline continues, additional wells may have to be drilled to meet water demand. Should pumping stabilize at about its present rate, the cone of depression would also tend to stabilize. Ground-water levels would probably reach equilibrium eventually, subject to seasonal fluctuation and long-term cycles of wet and dry periods. Long-term trends in ground-water levels may take many years to assess accurately, and the effects of a slowdown or halt in the pumpage growth curve will not be apparent overnight. It seems likely, however, that pumpage will continue to increase in the years ahead in response to more plant output and to new plants in the area.

New wells of large capacity upgradient from the wells at the Pittsburgh Plate Glass and Du Pont plants will inevitably intercept water moving toward these plants and will diminish their available supply. Indiscriminate development in this heavily pumped area could result in a critical lowering of ground-water levels. Ideally, additional large-scale ground-water withdrawal from the high-level outwash deposits would be planned and, if necessary, regulated to avoid serious local depletion of this important aquifer.

The high-level outwash deposits can yield additional large quantities of water in areas somewhat removed from present centers of pumpage. Ground-water levels 1 mi (1.6 km) or even less from the industrial plants have been little affected by pumping at the plants. Sites both north and south of these plants are underlain by thick outwash deposits above the bedrock and are candidates for future development. Test drilling and aquifer tests would provide a quantitative estimate of ground water available at specific sites.

GROUND WATER AVAILABLE AT OTHER SITES

Extensive sand and gravel deposits in the Circleville area offer possibilities for development of ground water. Especially promising would be sites near the Scioto River, where the outwash deposits are comparatively thick. Wells in such an environment, inducing infiltration of streamflow, supply nearly all large municipalities and industries in Ohio with water, notably at Dayton, Middletown, and Hamilton in the Great Miami River valley, and at Chillicothe and Piketon in the Scioto River valley. At Circleville, although large-scale withdrawal is possible, present ground-water demand is relatively low. For example, the Circleville municipal supply, about 1.5 Mgal/d (5.7×10^3 m^3/d), is pumped from two wells near the river in the north part of town. Nearby, the Container Corp. plant pumps about the same amount of water.

Areas where the outwash deposits are relatively thick can be determined approximately from the bedrock contours in figure 2. Typically, where the bedrock is deep the glacial deposits are correspondingly thick. The suitability of these deposits as aquifers can be established by test drilling and pumping.

Figure 2 shows also the locations of representative wells, including those outside the area of present industrial development. The well tables (table 1) together with the graphic logs indicate the character of the aquifers and drilling conditions elsewhere in the Circleville area. The tables are intended as guides in assessing ground-water availability in the entire area for rural, domestic, industrial, and municipal supply. The sand and gravel aquifers, including those interbedded with till, are extensive, and almost nowhere in the Circleville area is it difficult to obtain ground water in small to moderate amounts. Large ground-water supplies also are generally available in the more favorable areas.

CONCLUSIONS

Most pumpage in the Circleville area is from industrial wells tapping the high-level outwash deposits some distance from the Scioto River. The aquifer has proven to be dependable, prolific, and capable of additional development in the same general area. These deposits, however, are not the only nor the largest source of ground water in the Circleville area. The source capable of yielding water in amounts far exceeding present demand is the sand and gravel outwash close to the Scioto River. Induced infiltration of streamflow can increase well yields several times over those of similarly constructed upland wells.

On the basis of the information in this report and, perhaps, with better knowledge of the hydrologic system, new wells could be located in the more favorable areas and pumped at rates designed to avoid long-term overdraft. Because local ground water is especially abundant, it seems unlikely that the Circleville area will experience water shortages.

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